# Current standing of Space Weather forecasting

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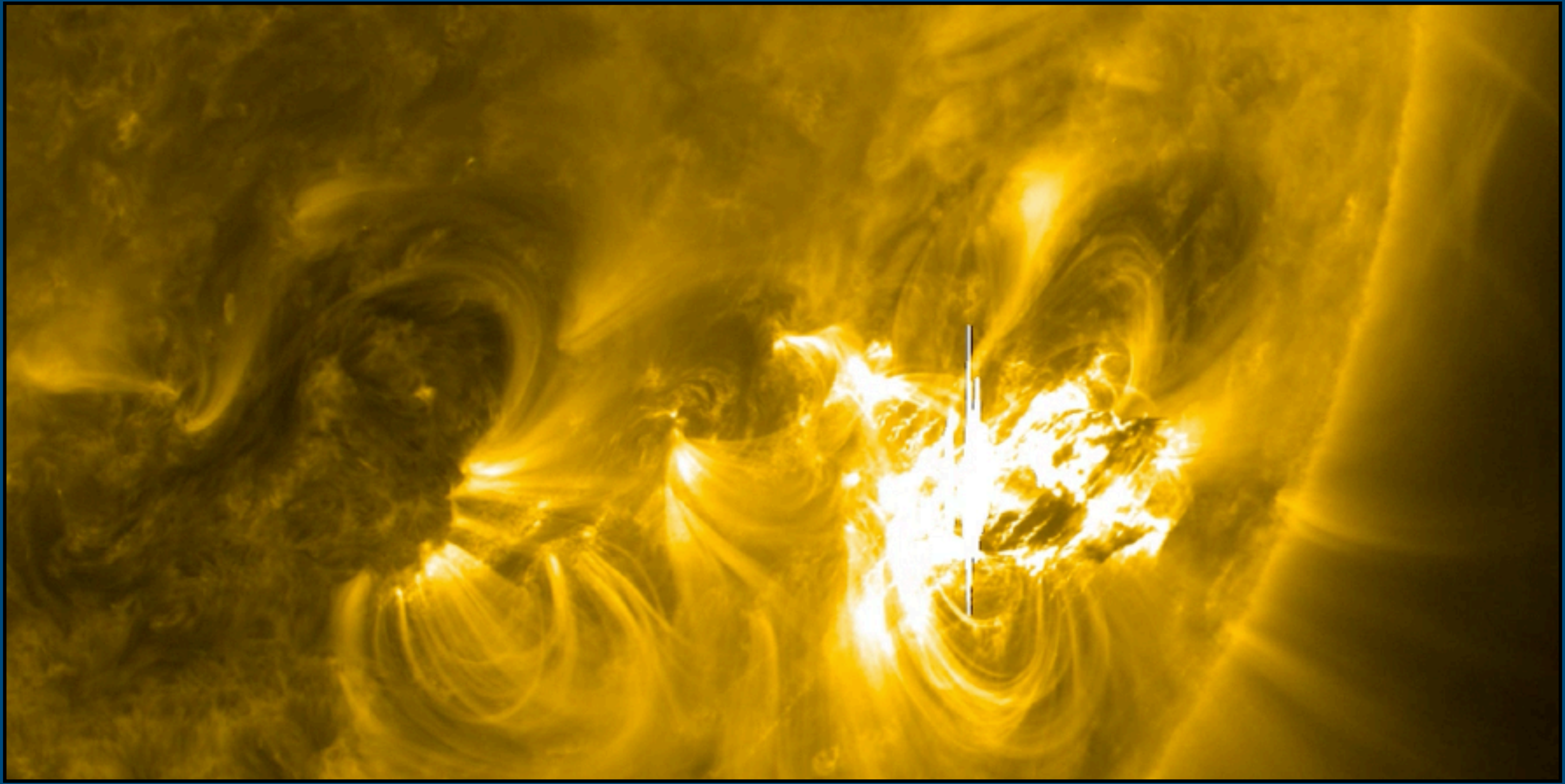
*Thanks to: Luciano Rodriguez, Spiros Patsourakos and Manolis Georgoulis for useful discussions*



# Flare forecasting

Let’s focus on the BIG flares ...

# It’s not *that* hard to do a moderately good job

Prediction for tomorrow
(and all the coming days):
No >M-class X-ray flare will
occur during the next 24 hr

**90%**
**success**
**rate!**

simply because,
90% of the Active Regions don’t
produces flares of >M-class

*Barnes & Leka, ApJL107 (2008)*

Central question is:

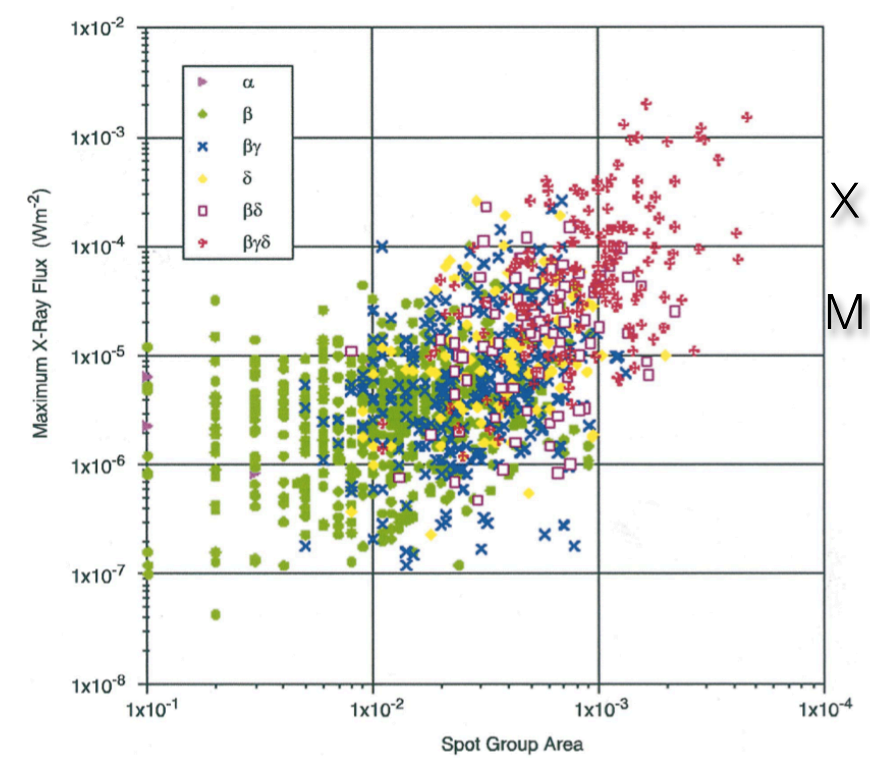
Can we do better?

*Yes, we can!*

*But it's damn hard!*

# Big flares need ARs with enough magnetic complexity

*Künzel et al. (1960)*



Necessary condition:

100% of >X4-flares occur in **βγδ**

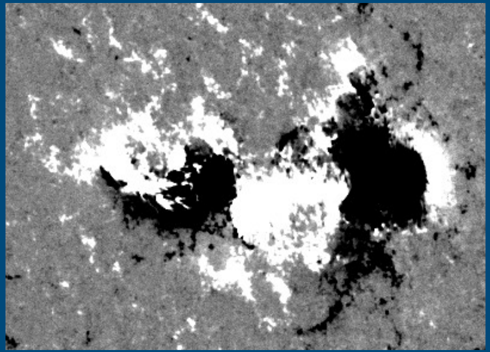
82% of all X-flares occur in **βγδ**

Sufficient condition?

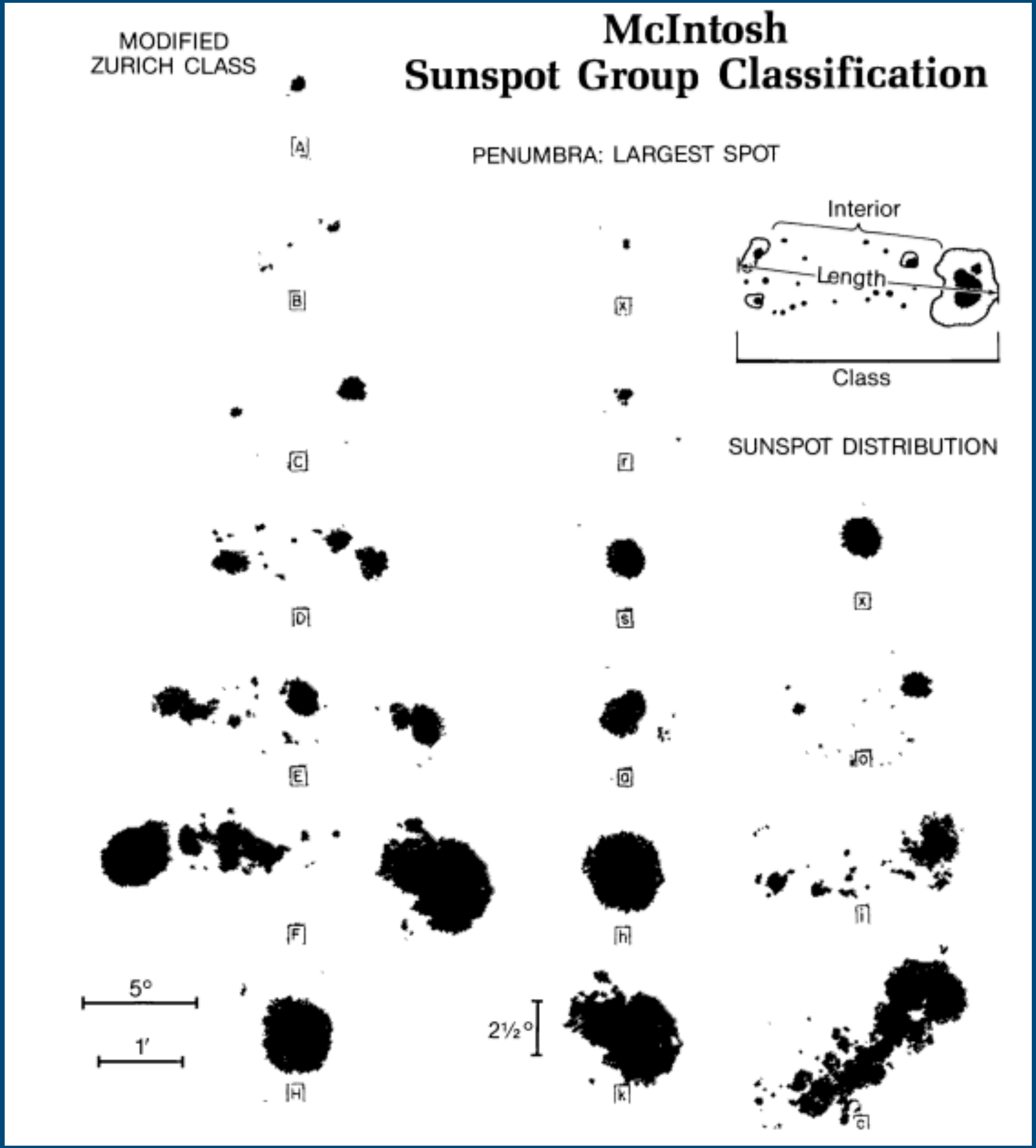
Large **βγδ** groups have only 40% chance to produce X flare.

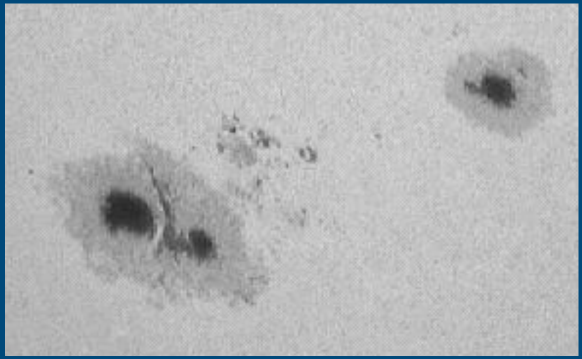
*Sammis et al. (2000)*

Mount-Wilson classification

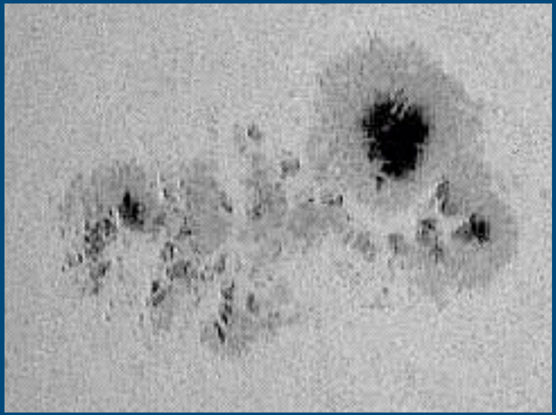


# McIntosh Sunspot classification





Fko 25% M-flare

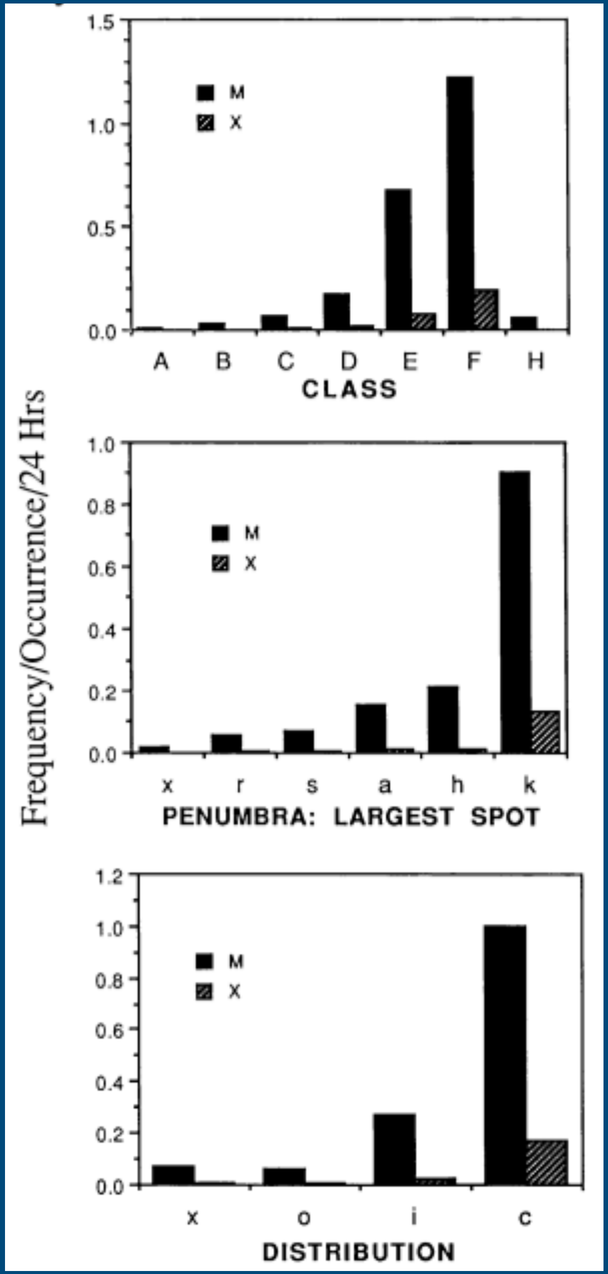


Ekc 52 % M-flare

*McIntosh (1966, 1990)*

# McIntosh vs flares

*McIntosh (1990)*
*Gallagher (2002)*
*Norquist (2011)*



well developed ARs

Large area of strong field

Asymmetric sunspot

Magnetically complex (delta)

many spots in between

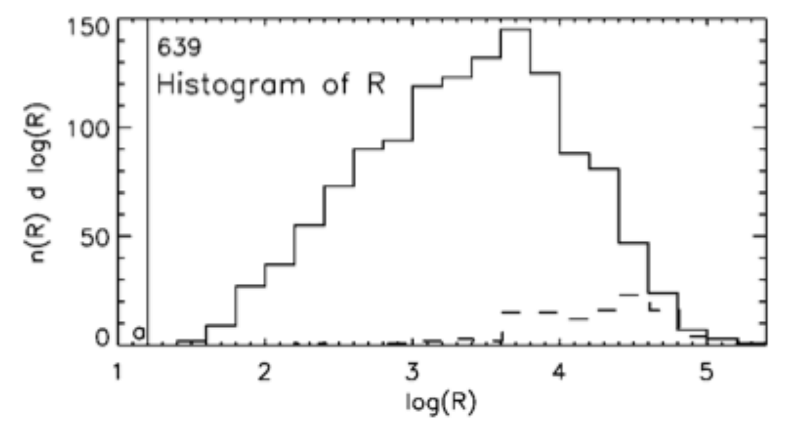
Strong gradient (shear)

# Modern variations on the theme

- Total unsigned flux: traditional parameter
- R-value (Schrijver 2007)
- Bipole region separation (Chumak 1987; Guo 2006)
- PIL length (AR complexity)
- GWILL (Mason & Hoeksema, 2010)
- non-potentiality index (Falconer)
- degree of polarity

# R-value

*Schrijver (2007)*



80% sure about ~1% of ARs

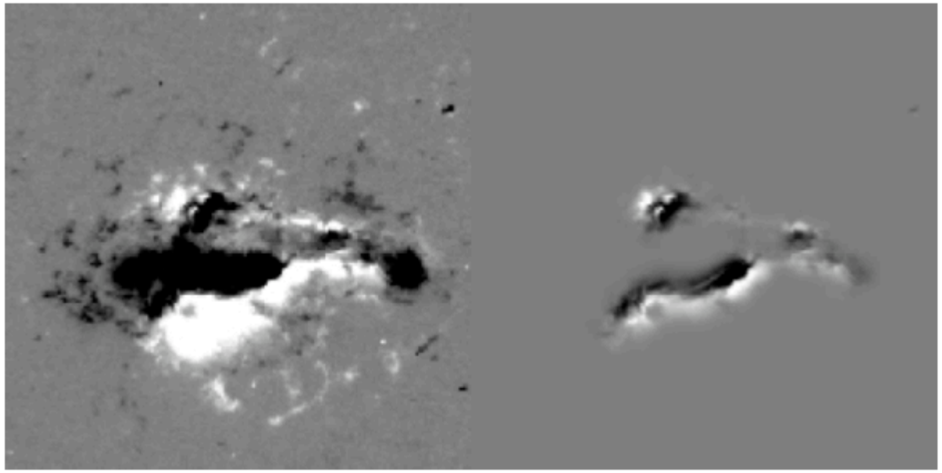
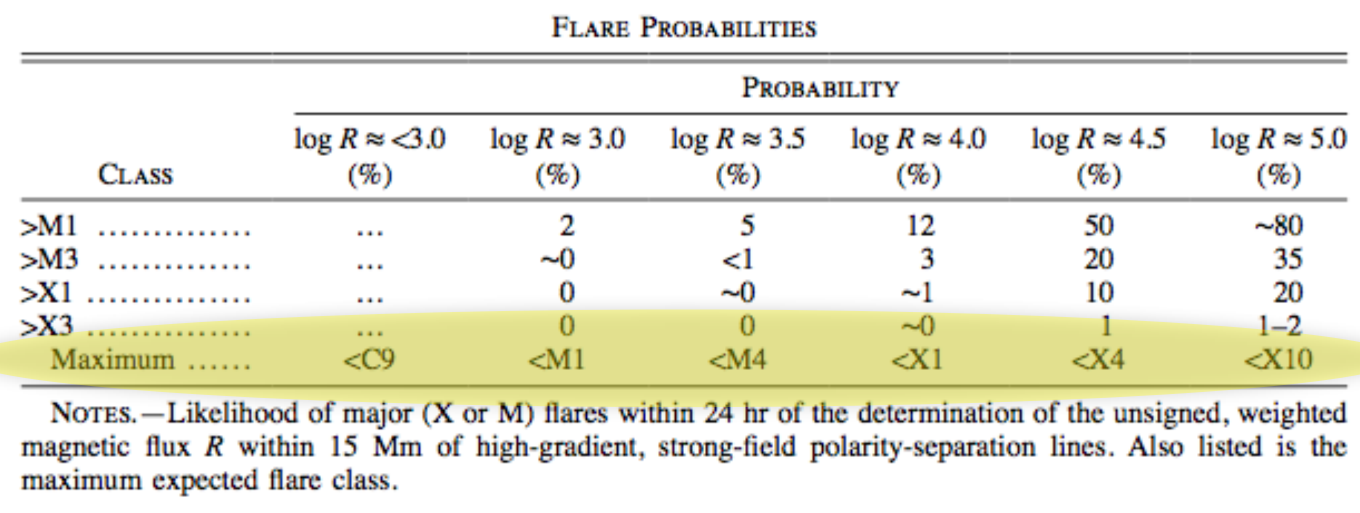


FIG. 1.—*Left*: Example of a *SOHO* MDI magnetogram (cutout of 160 × 160 pixels of 2″ square) around the time of the M4.6 flare on 2005 September 14 10 UT (log $R = 5.03$). *Right*: Magnetogram multiplied with the weighted map $W$ of the field near high-gradient, strong-field, polarity-separation lines, which, after summing their absolute values, yields $R$.



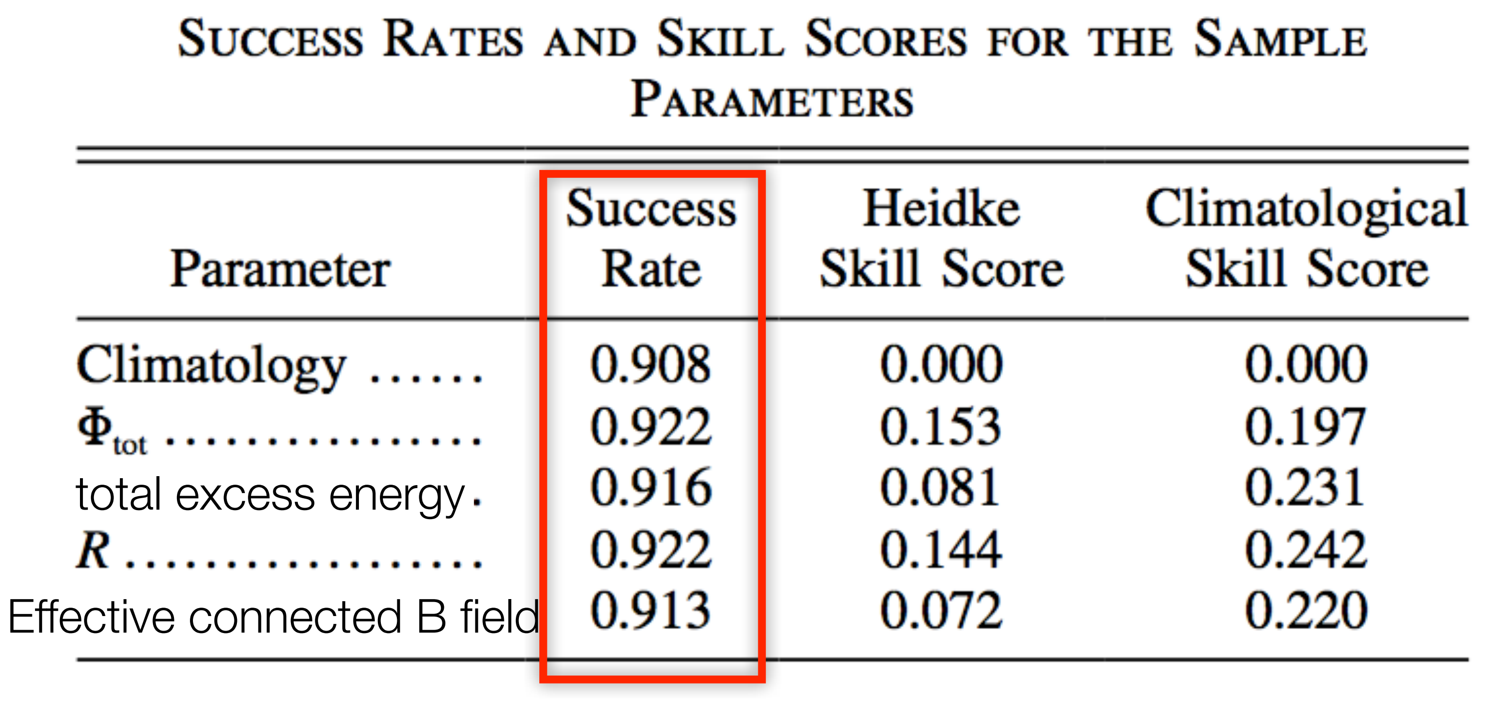
FLARE PROBABILITIES

| | PROBABILITY | | | | | |
|---|---|---|---|---|---|---|
| CLASS | log $R \approx$ <3.0 (%) | log $R \approx$ 3.0 (%) | log $R \approx$ 3.5 (%) | log $R \approx$ 4.0 (%) | log $R \approx$ 4.5 (%) | log $R \approx$ 5.0 (%) |
| >M1 .............. | ... | 2 | 5 | 12 | 50 | ~80 |
| >M3 .............. | ... | ~0 | <1 | 3 | 20 | 35 |
| >X1 ............... | ... | 0 | ~0 | ~1 | 10 | 20 |
| >X3 ............... | ... | 0 | 0 | ~0 | 1 | 1–2 |
| Maximum ...... | <C9 | <M1 | <M4 | <X1 | <X4 | <X10 |

NOTES.—Likelihood of major (X or M) flares within 24 hr of the determination of the unsigned, weighted magnetic flux $R$ within 15 Mm of high-gradient, strong-field polarity-separation lines. Also listed is the maximum expected flare class.

# Success rates

*Barnes & Leka (2008)*



SUCCESS RATES AND SKILL SCORES FOR THE SAMPLE PARAMETERS

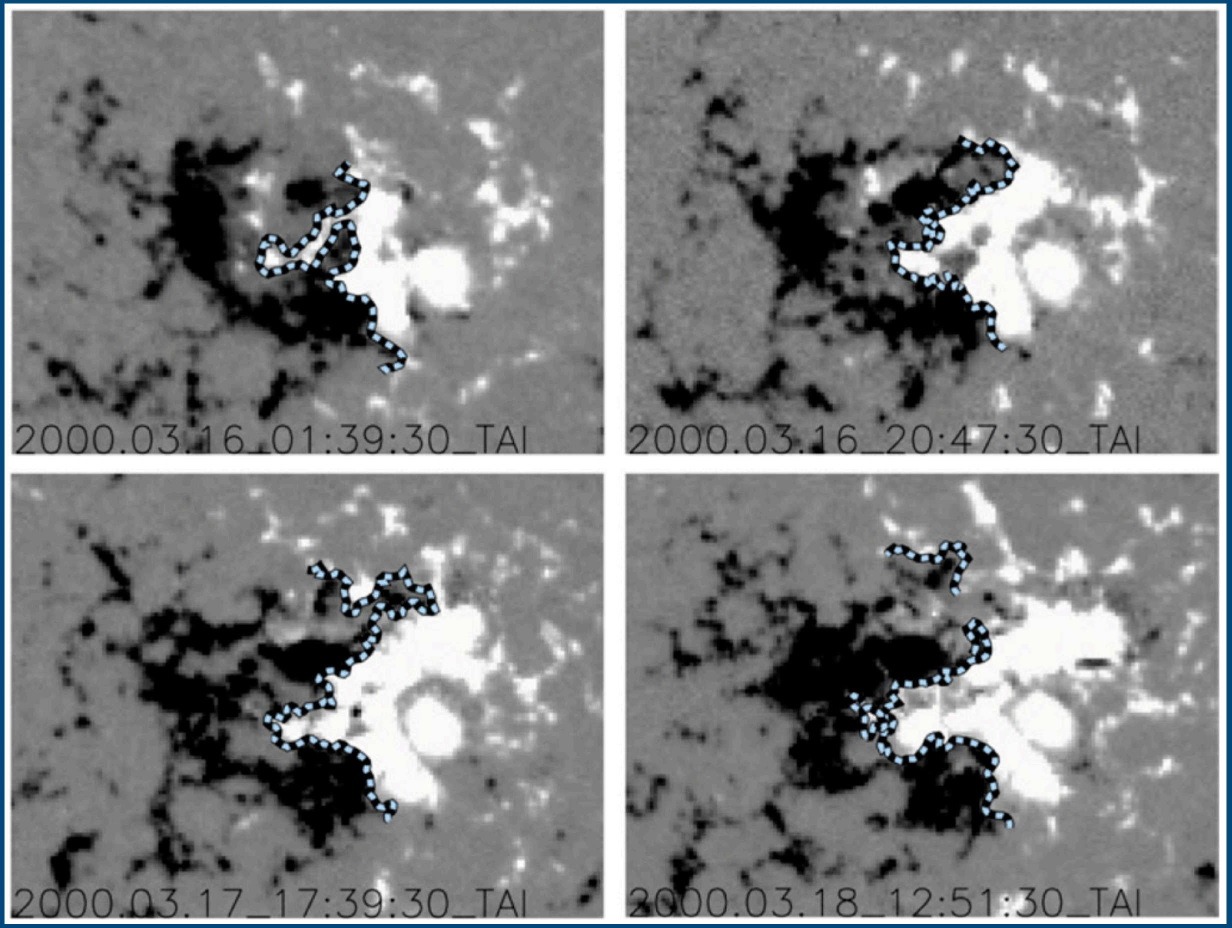
| Parameter | Success Rate | Heidke Skill Score | Climatological Skill Score |
|---|---|---|---|
| Climatology | 0.908 | 0.000 | 0.000 |
| $\Phi_{\rm tot}$ | 0.922 | 0.153 | 0.197 |
| total excess energy | 0.916 | 0.081 | 0.231 |
| $R$ | 0.922 | 0.144 | 0.242 |
| Effective connected B field | 0.913 | 0.072 | 0.220 |

*Leka & Barnes (2003)*

*Schrijver (2007)*

*Georgoulis & Rust (2007)*

# Gradient weighted PIL length



**GWILL**:

PIL length
$\otimes$
gradient across it

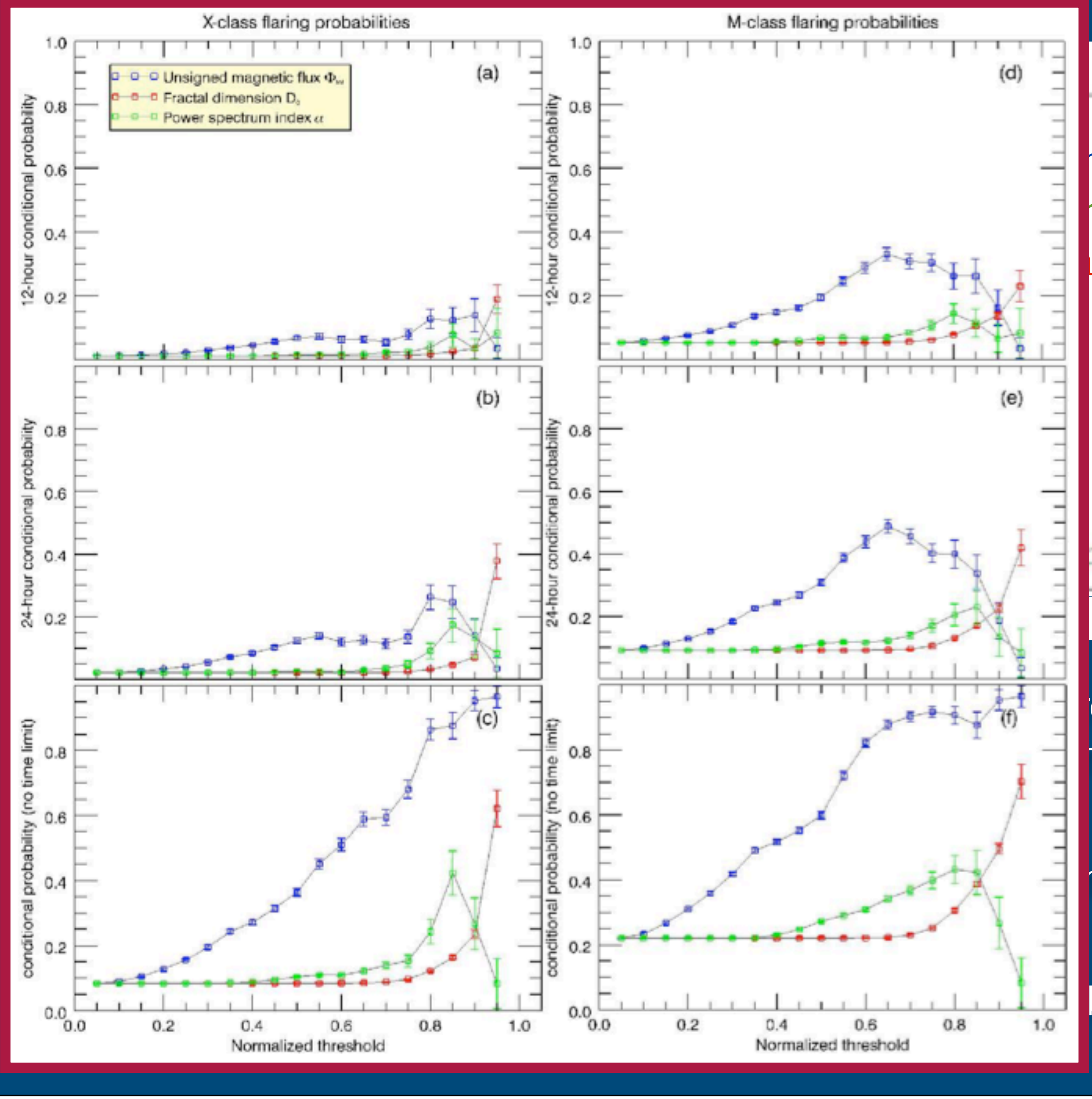
Include change in time!

Long PIL → complex magnetic field
Strong field gradient → shear or twist

Heidke Skill score = 0.69

*Mason & Hoeksema (2010)*

# Alternative methods: fractals

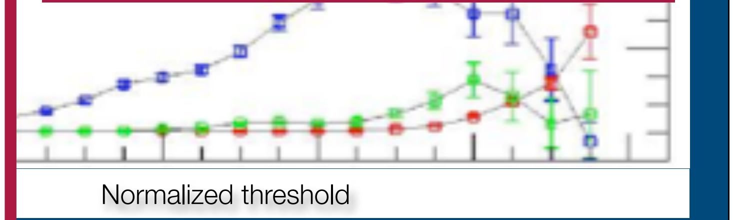


We know it will flare, but we don't know when!

he

r S

l



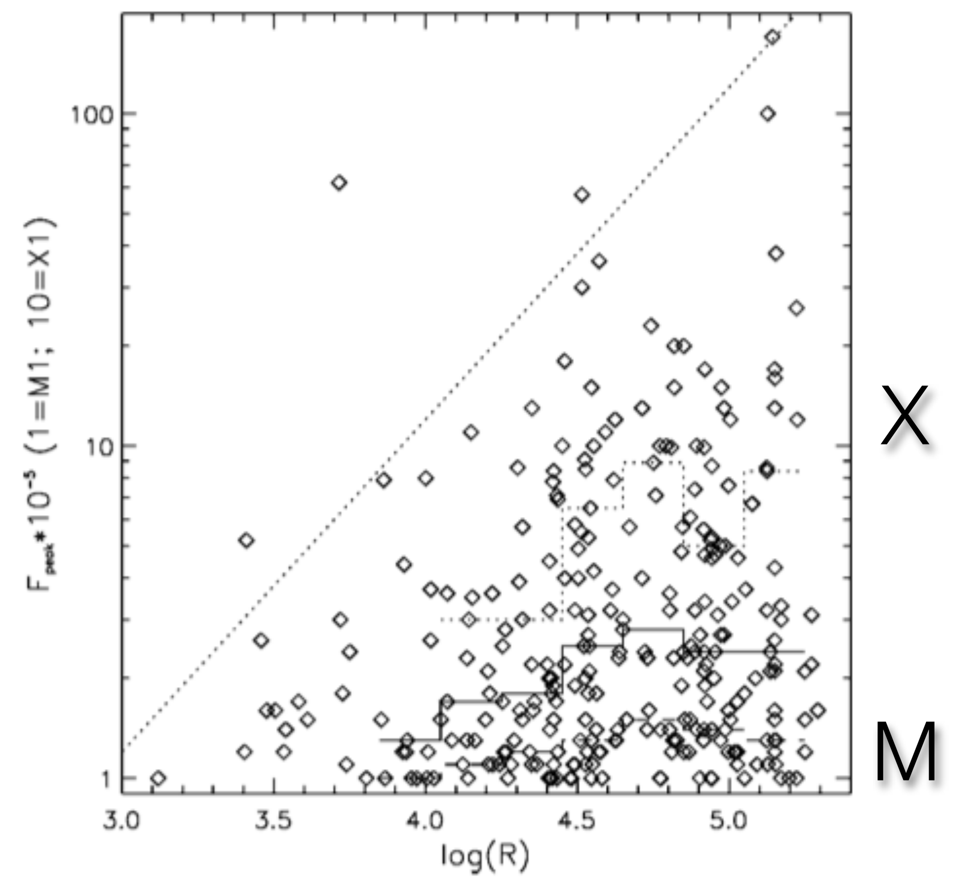
ee and multiscale parameters:
ension & power-spectrum

ore fractal, multifractal or

better predictor.

*Georgoulis (2011)*

# Probabilistic or deterministic?

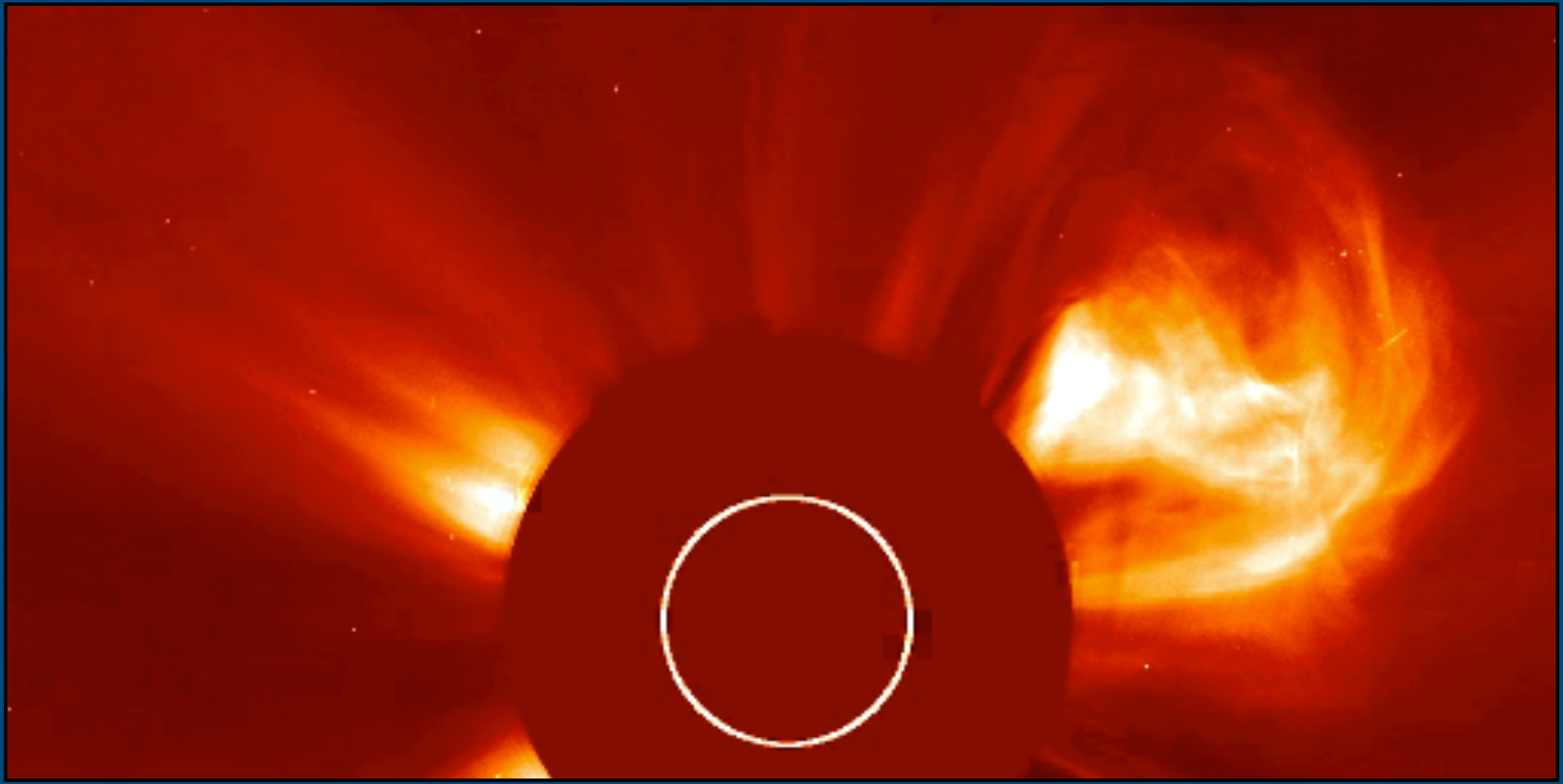


*Schrijver (2007)*

Flare energy is drawn randomly from a power-law that extends up to a maximum value set by the available energy

or

Flare energy = f(p)



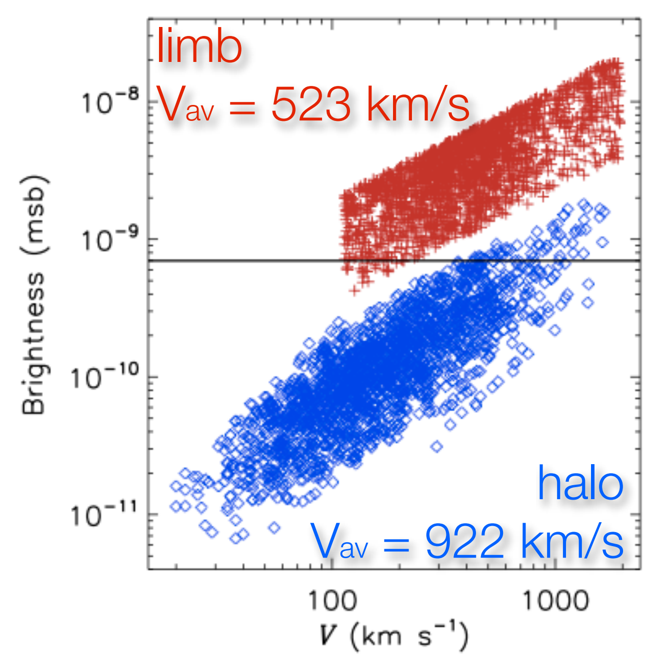
# Coronal Mass Ejections

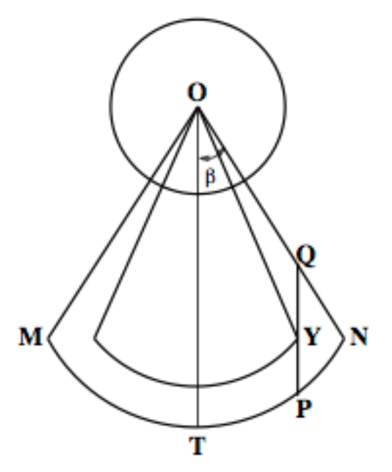
# Are halo CMEs special?

## Yes

Yashiro (2004):
Averaged, observed halo CMEs are ~2 x faster than normal CMEs.

Fainshtein (2006):
Averaged, observed halo CMEs are wider than normal CMEs.



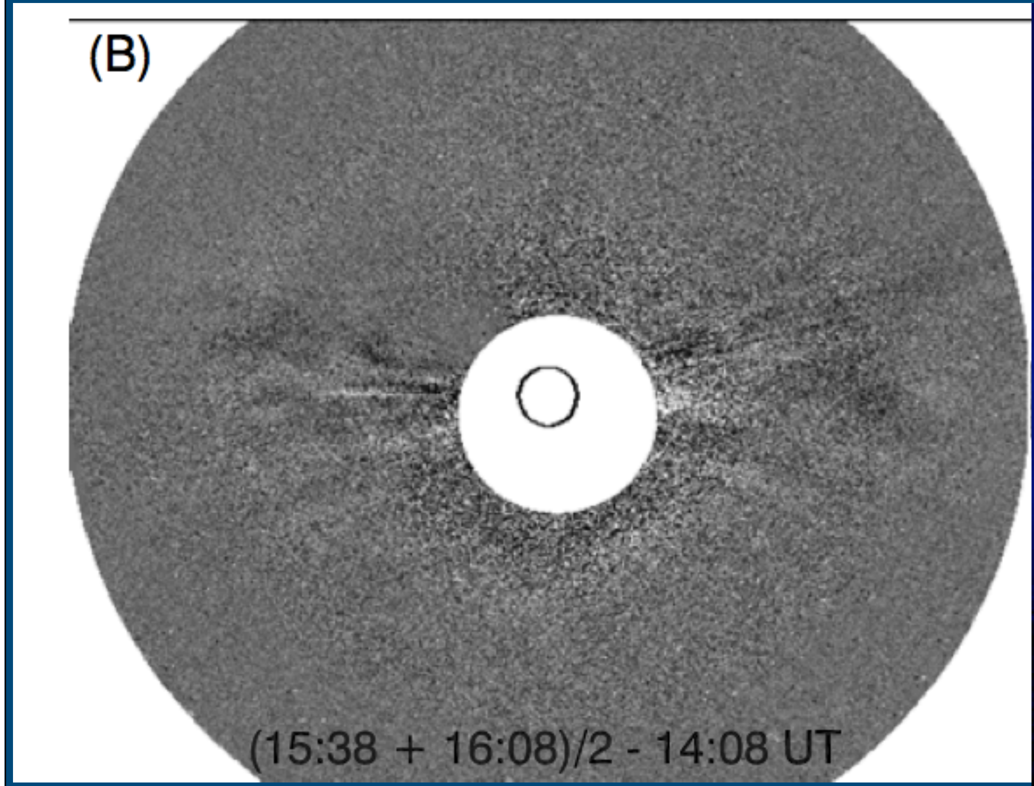


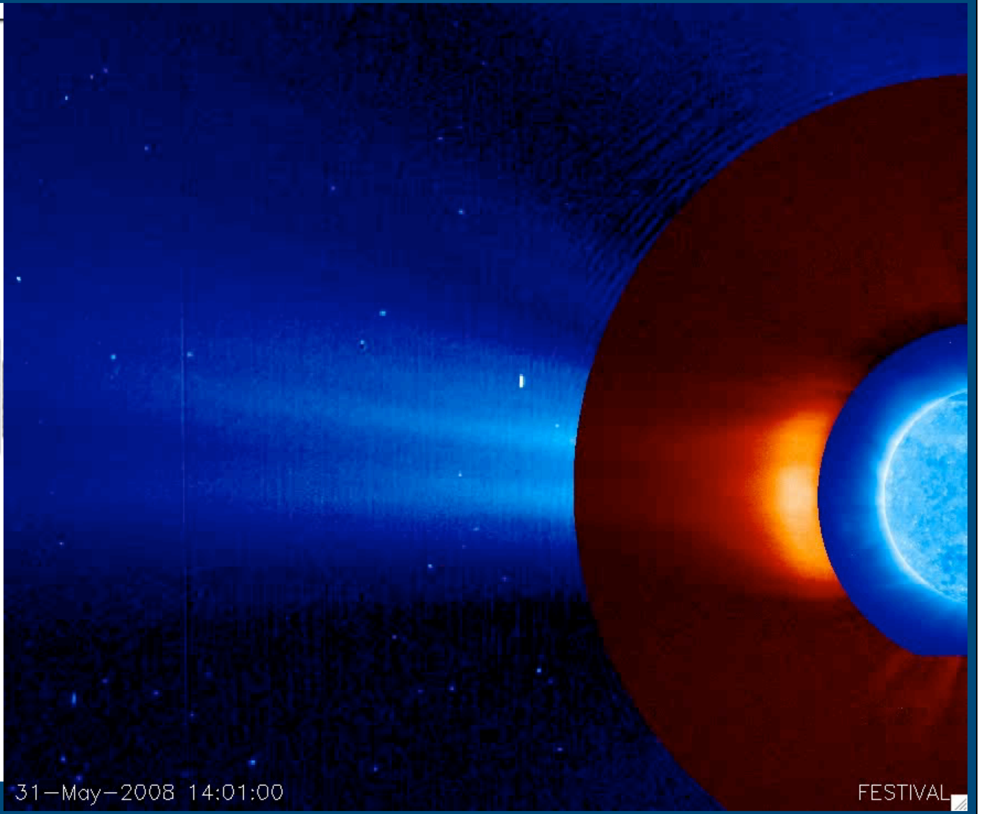
## No

Zhang Q.M. (2010):
Slow CMEs are less bright and thus not observable as halo.

Zhang Q.M. (2010):
Wider CMEs are
(1) closer to plane-of-sky and thus better detectable,
(2) detected closer to the photosphere

# STEREO

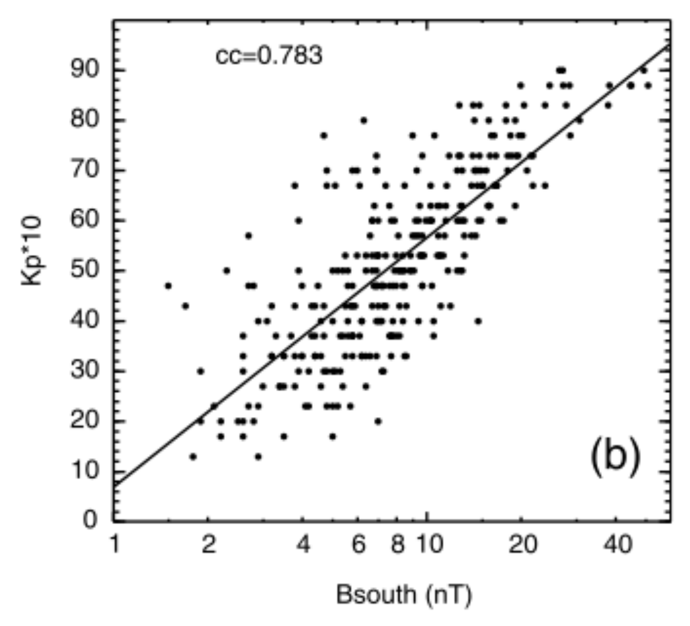




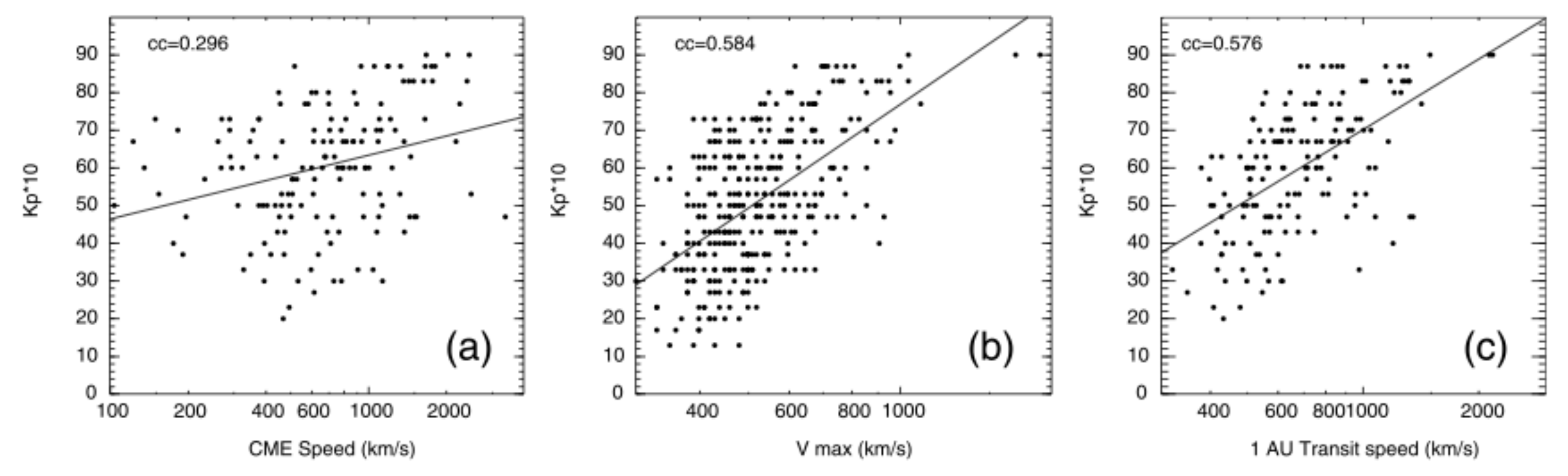
*Robbrecht (2009); Ma (2010)*

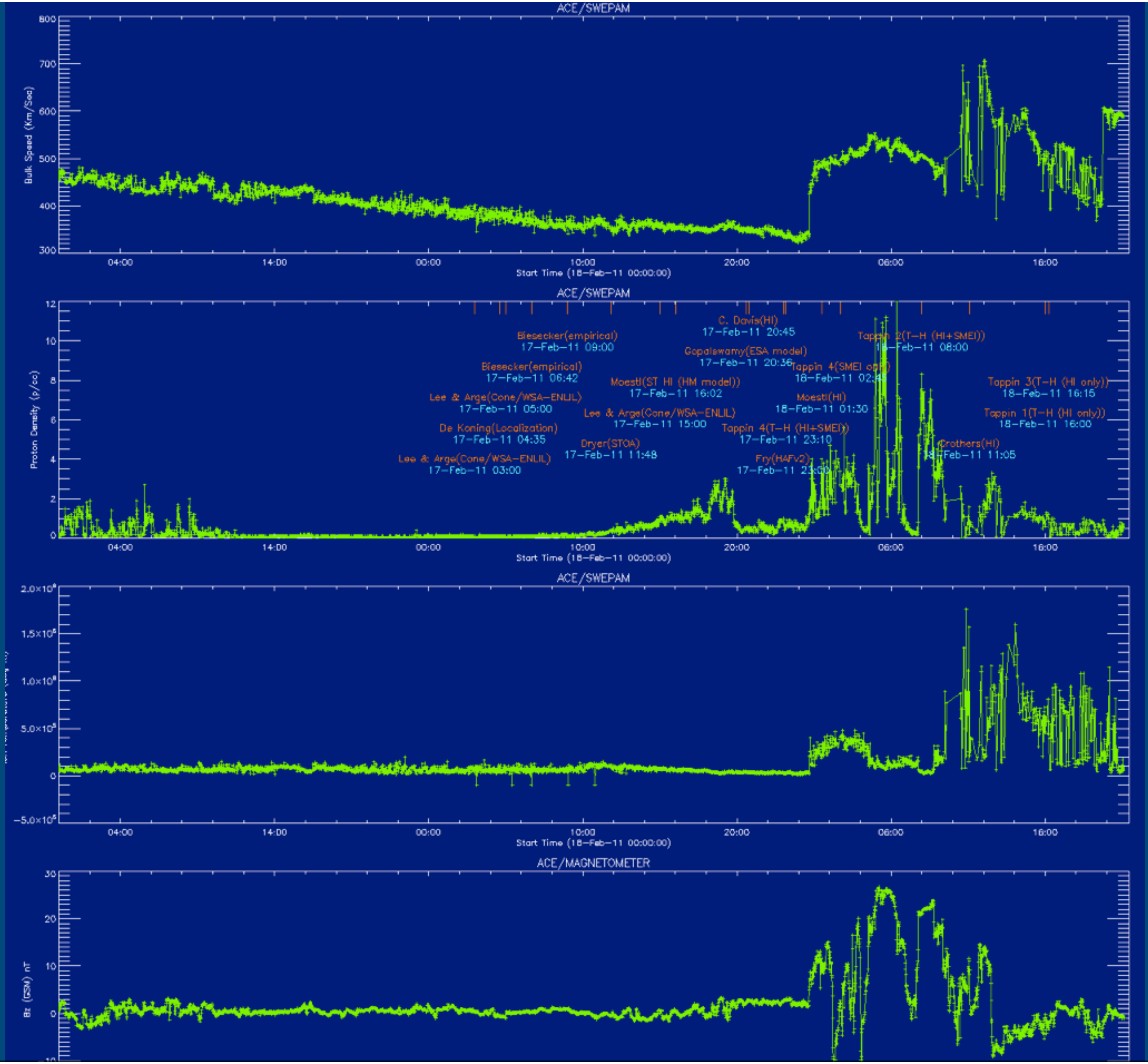
1/3 stealth CME during past solar minimum
CME Speeds < 300 km/s

# geoeffectiveness of CMEs



*Richardson & Cane (2011)*




ACE/SWEPAM
Bulk Speed (Km/Sec)
800
700
600
500
400
300
04:00
14:00
00:00
10:00
20:00
06:00
16:00
Start Time (18-Feb-11 00:00:00)
ACE/SWEPAM
Proton Density (p/cc)
12
10
8
6
4
2
0
C. Davis(HI)
17-Feb-11 20:45
Biesecker(empirical)
17-Feb-11 09:00
Tappin 2(T-H (HI+SMEI))
18-Feb-11 08:00
Gopalswamy(ESA model)
17-Feb-11 20:36
Biesecker(empirical)
17-Feb-11 06:42
Tappin 4(SMEI only)
18-Feb-11 02:45
Moestl(ST HI (HM model))
17-Feb-11 16:02
Tappin 3(T-H (HI only))
18-Feb-11 16:15
Lee & Arge(Cone/WSA-ENLIL)
17-Feb-11 05:00
Moestl(HI)
18-Feb-11 01:30
Lee & Arge(Cone/WSA-ENLIL)
17-Feb-11 15:00
Tappin 1(T-H (HI only))
18-Feb-11 16:00
De Koning(Localization)
17-Feb-11 04:35
Tappin 4(T-H (HI+SMEI))
17-Feb-11 23:10
Dryer(STOA)
17-Feb-11 11:48
Crothers(HI)
18-Feb-11 11:05
Lee & Arge(Cone/WSA-ENLIL)
17-Feb-11 03:00
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Start Time (18-Feb-11 00:00:00)
ACE/MAGNETOMETER
Bz (GSM) nT
30
20
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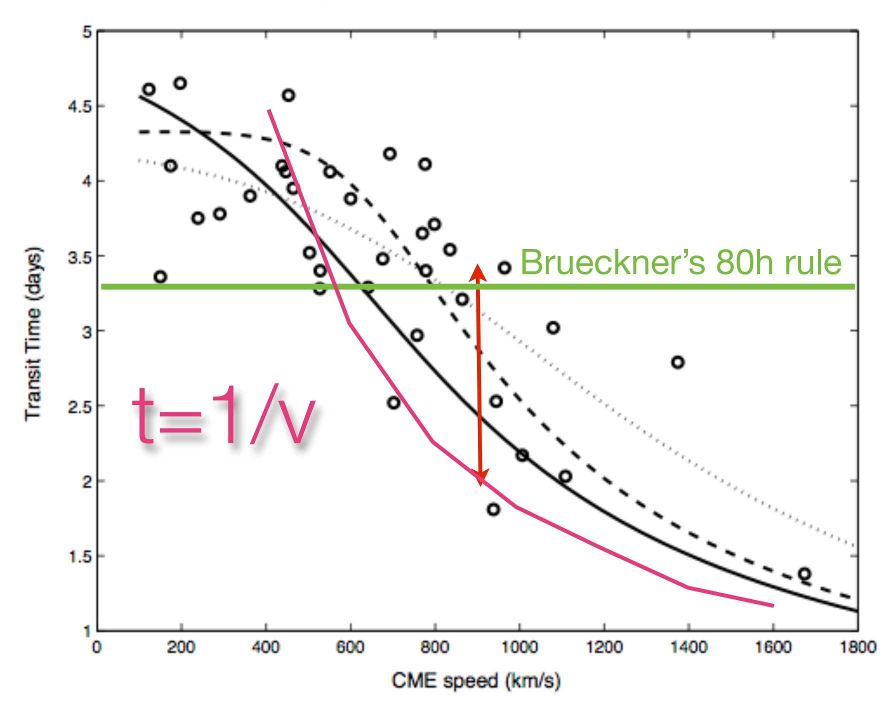
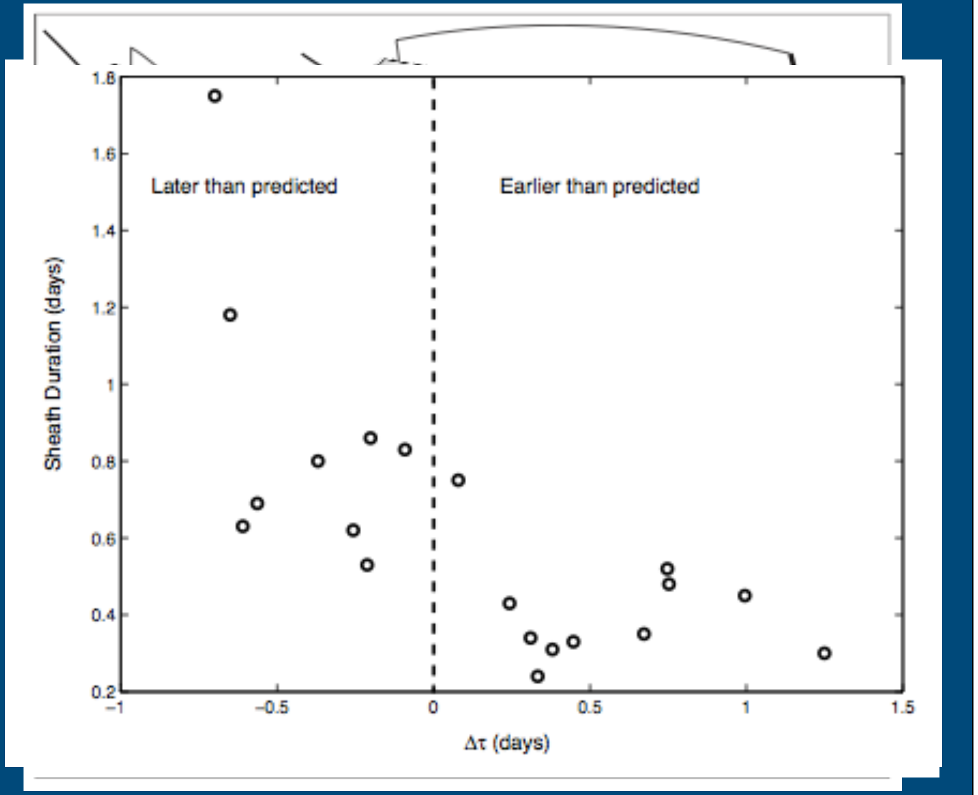
0
-10

# CME travel times

*Owens & Cargill (2004)*





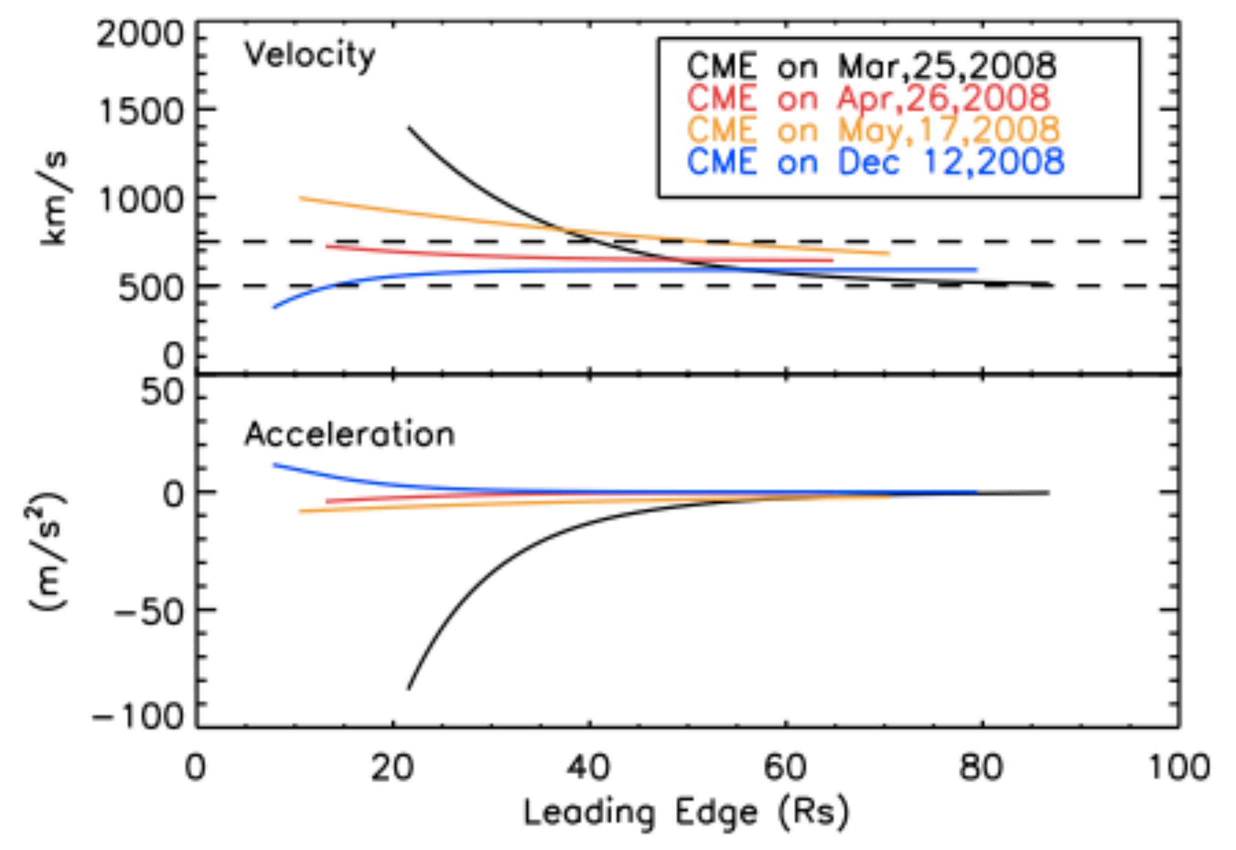
## Possible sources of error:

- ~~CME initial speed (projection effects)~~
- ~~Constant background SW speed~~
- ICME - sheath

## Tests:

- Quadrature observations / onset time
- Use actual SW speed
- sheath region vs travel time

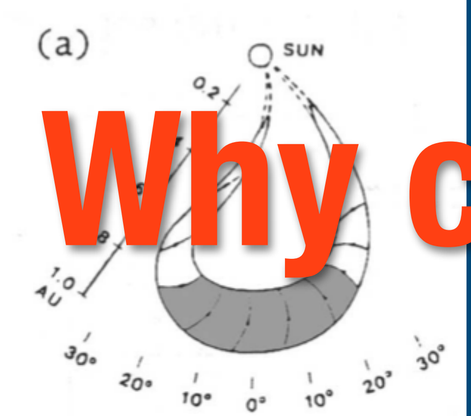
# CME travel times



*Poomvises (2010)*

Exponential function approaching asymptotic value around 60 Rsun

# Predicting “Bz”

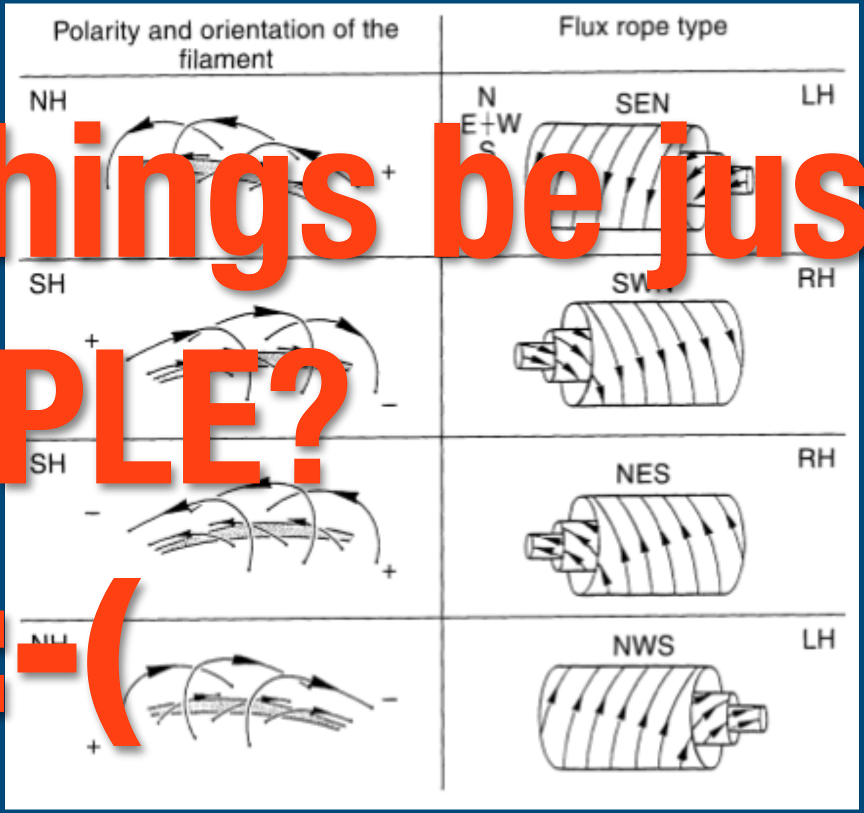


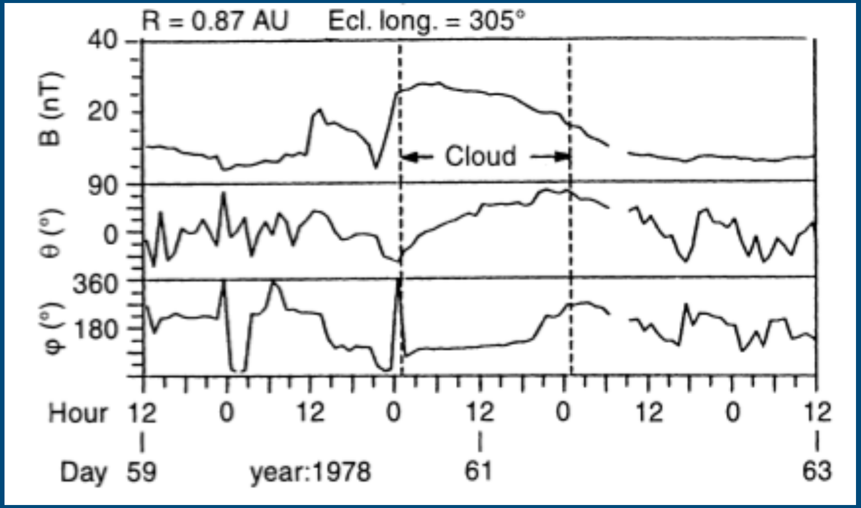
*Marubashi (1997)*

**Why can’t things be just SIMPLE?**

**:-(**

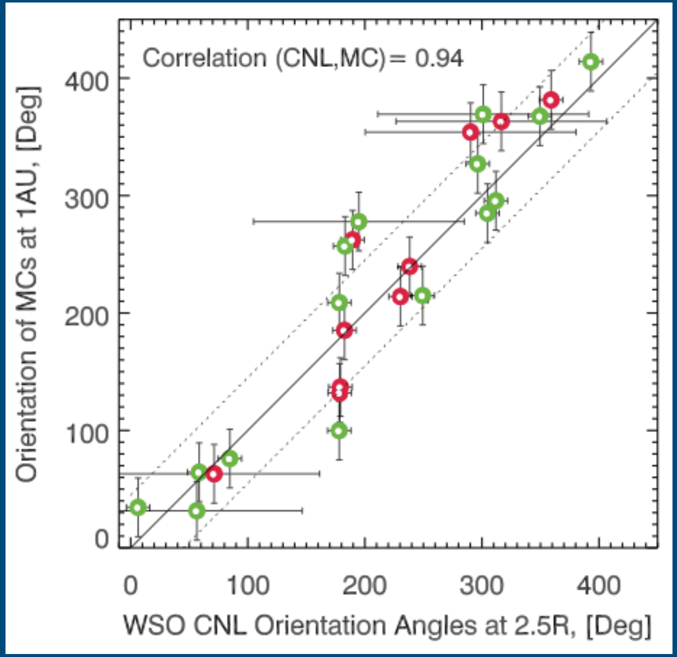
*Bothmer & Schwenn (1998)*

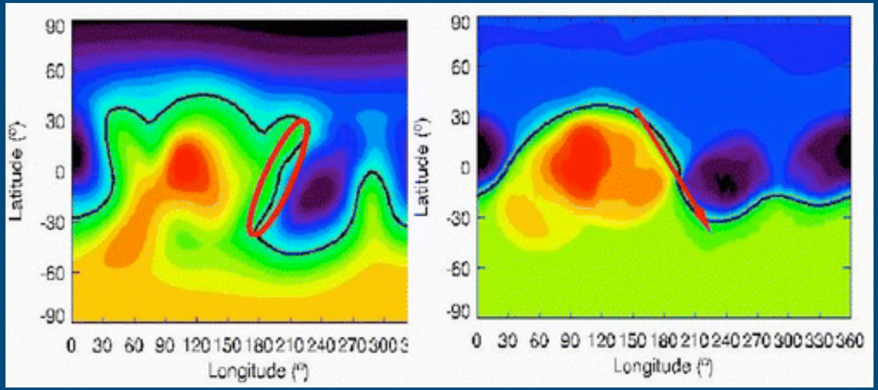




“Conservation of magnetic helicity”

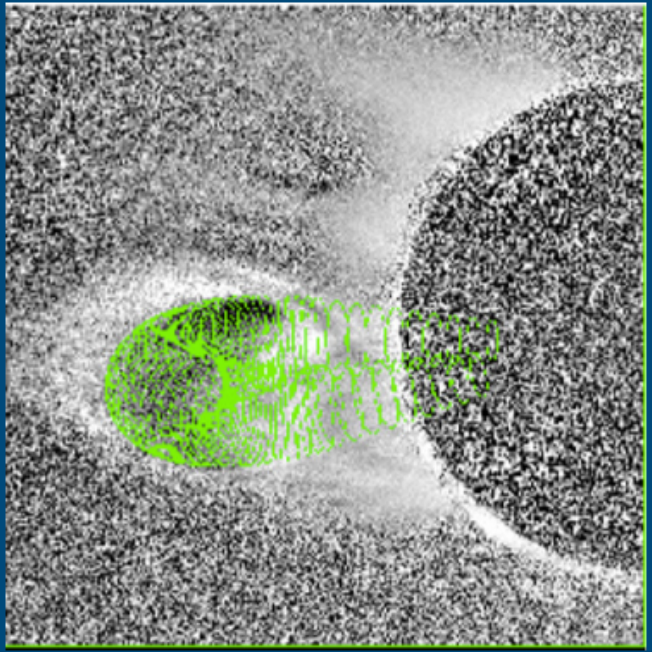
# CMEs can rotate





Ambient corona defines final tilt angle

*Yurchychyn (2008)*

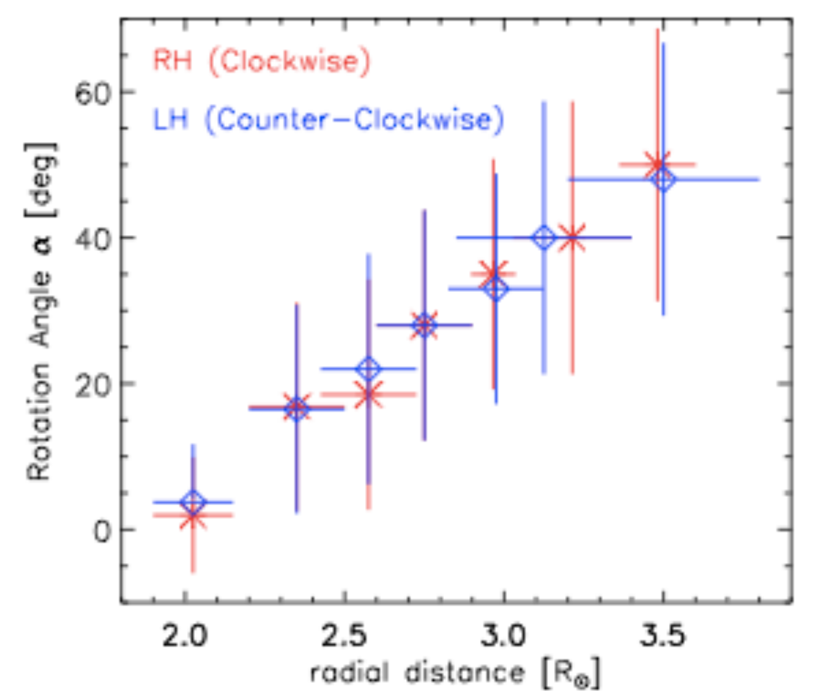


Direct observation of CME rotation beyond 15 Rsun

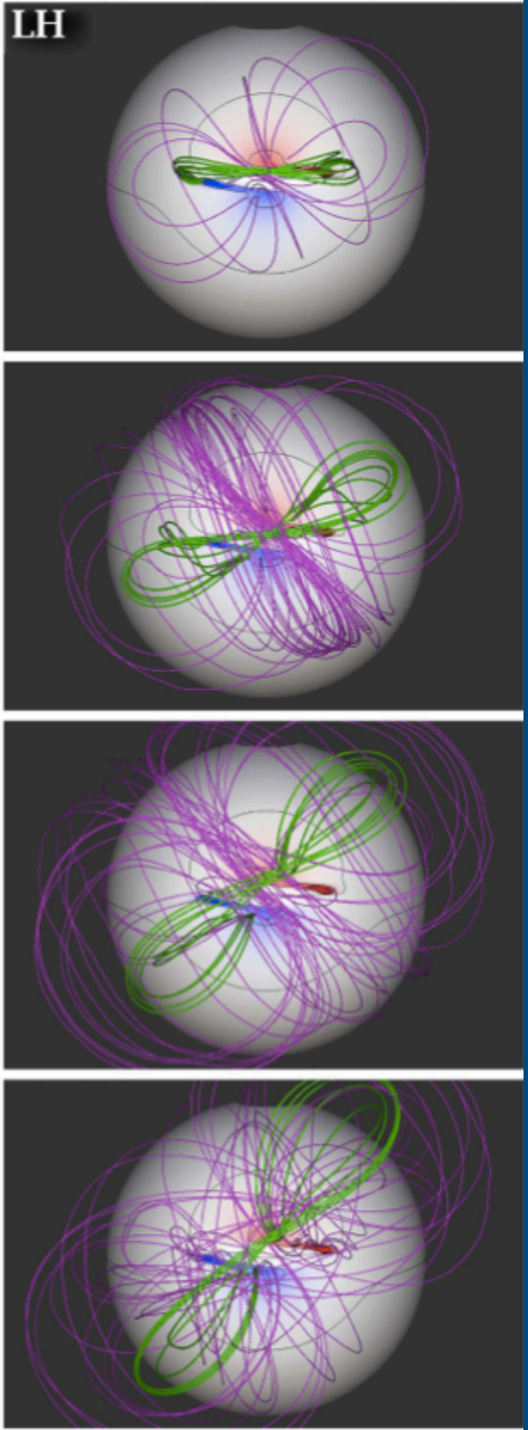
*Vourlidas (2011)*

# CMEs can rotate

"Sigmoidality" defines rate and amount of rotation



*Lynch (2009)*



# Conclusions

Flares

- Combine flare probability methods
- Barnes & Leka (2007): predictive capability based on longitudinal magnetograms is not very strong
- Pre- and post-flare changes in photosphere are limited, even for X-class flares

CMEs

- Estimate thickness of ICME sheath regions
- CME trajectory: difficult without stereo observations
- CME rotation: predict Bz

Thank You!